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Soil and Water Conservation Research Division

In cooperation with the
Minnesota Agricultural Experiment Station
and the
St. Anthony Falls Hydraulic Laboratory
University of Minnesota

LET'S DEMONSTRATE HYDRAULIC PHENOMENA

A guide for the operation and use of
the portable demonstration channel and
models of hydraulic structures

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THE CHANNEL AND ITS OPERATION

The demonstration channel has been designed to operate when its power cable is plugged into a 115-volt, 60-cycle, single phase outlet. Any convenient outlet of this type will do. A clip is provided on the plug to ground the apparatus, thus preventing possible electrical shocks.

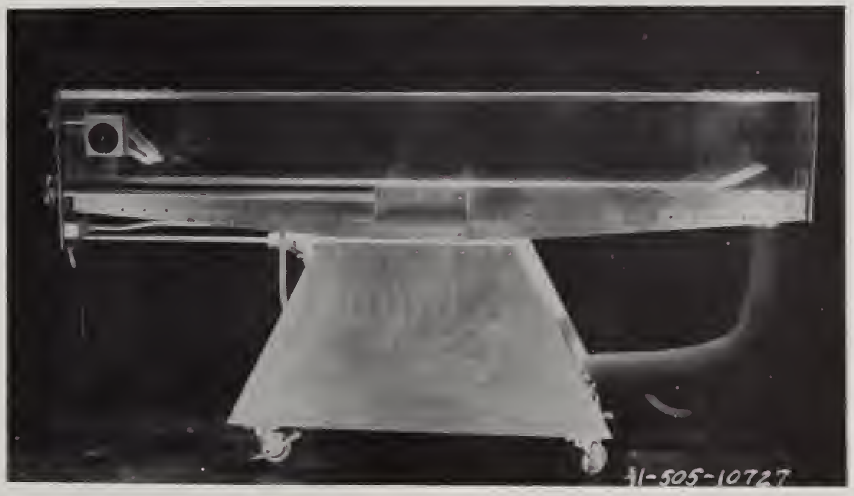

Fig. 1.--Hydraulic Demonstration Channel

The reservoir at the bottom of the apparatus holds the water for operating the channel and should be filled to within 3 to 4 inches of the top. To open the reservoir for filling, slide the cover toward the headgate. Be sure the drain valve is closed.

When in operation, water is pumped through the flow discharge control valve, under the headgate at the left (as you view Fig. 1), through the channel, and is returned to the reservoir via the tailgate. This recirculation continues throughout the operation of the channel.

To drain water from the reservoir, attach a hose to the connection provided under the reservoir at the downstream end and open the valve.

Although most of the apparatus is made of rust-proof material, some rust may develop and discolor the water. Rusting can be prevented by adding two pounds of borax to the supply tank (a 0.1% solution).

Now, let's discuss the controls. Since they are all on the headgate end of the channel (see Fig. 2), this will be referred to as the "control panel." Let's follow the water through the channel, discussing the various parts as they are passed.

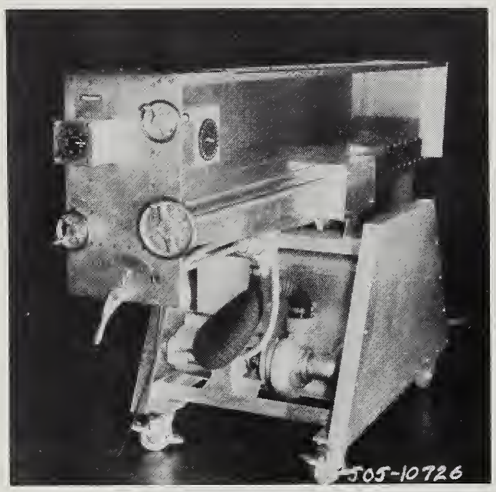

Fig. 2.--Demonstration Channel Showing Control Panel, Pump and Reservoir

The valve which controls the water discharge is located under the channel floor. The rate of discharge is regulated by the valve handle which extends below the control panel (Figs. 2 and 3). The discharge valve indicator is graduated from 0 (closed) to 6 (fully open). Care should be taken when increasing the rate of discharge as the valve is very sensitive--a small adjustment makes a big change in discharge. For the demonstrations that will be discussed, a valve setting of from 0.5 to 2 is sufficient.

The headgate, located at the upstream end of the channel, fits tightly against the sides of the channel. The gate moves much more easily when there is water in the channel to "lubricate" the rubber seals. The headgate control is located at the upper right on the control panel (Figs. 2 and 3). The handwheel opens the gate when turned clockwise and closes it when turned counterclockwise. The headgate can be moved to almost any angle within a complete circle but extreme angles are seldom, if ever, used or useful in these demonstrations. To note the angle of the headgate, one need only look at the indicator which is located on the front of the channel (Fig. 4).

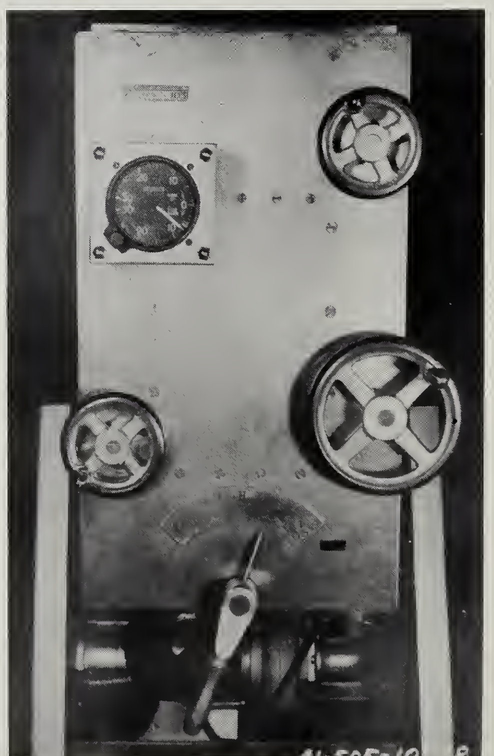

Fig. 3.--Control Panel

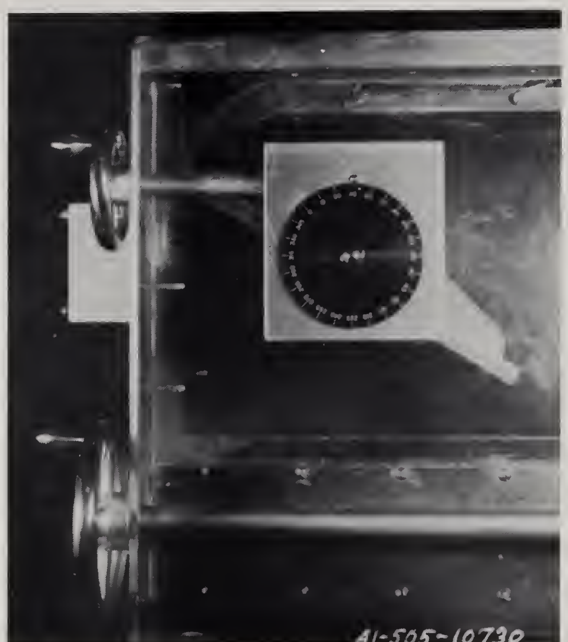

Fig. 4.--Headgate Position Scale

It is not meant that the headgate be used to regulate the amount of flow of water into the channel. The discharge valve has been provided for this purpose. To provide a fast, shooting flow, as required to demonstrate the hydraulic jump, the headgate should be open only about 1/2 inch (15 degrees on the indicator dial). An opening of 4 to 6 inches (60 to 90 degrees) is best for the demonstration of the models of hydraulic structures.

The large handwheel provided at the lower right of the control panel (Fig. 3) is to regulate the channel slope. The actual slope is shown by the channel slope indicator at the upper left of the control panel (Fig. 3). Although the channel can be tipped 15 degrees up or down, normally the slope should not exceed plus or minus 6 degrees. The slope adjustment is necessary because some of the models have been designed to be used in a sloping channel.

The tailgate, which can be seen in Fig. 1, is controlled by the small handwheel at the lower left of the control panel (Fig. 3). A scale of slope positions is on the back side of the channel as shown in Fig. 5. Position 0 is perpendicular to the channel floor while Position 6 is parallel to the floor. You will note that the tailgate does not extend to the top of the channel. This provides ample space to prevent water from overflowing the

Fig. 5.--Tailgate Position Scale

channel under ordinary operating conditions. Tailwater depth is controlled by using the tailgate to dam up the water and hold it at the desired depth.

With the exception of the power switch located at the lower right hand corner of the control panel (Fig. 3), this concludes the discussion of the controls. With the discharge valve closed, turn the switch on and the demonstration can begin.

Your attention is called to the table on page 28 which gives approximate control settings for the operation of the various models at their designed discharge.

The demonstration channel was constructed, for the most part, of aluminum and plastic, at a cost of about $2000.

The models of hydraulic structures which fit into the channel were constructed in the St. Anthony Falls Hydraulic Laboratory shop. They are made of plastic at a cost of about $462, most of which was labor. This material was chosen to make it possible to easily view the flow of water in and through the structures. If the models are broken, they can be repaired by cementing the break with chloroform.

THE MODELS AND THEIR DEMONSTRATION

Most of the following descriptions of the hydraulic phenomena and of the models of hydraulic structures to be used with this channel will include the positions of the controls at which the most effective demonstration of each can be made. However, a little trial-and-error manipulation will show what happens when the flow is greater or less than the design flow or when the tailwater depth is greater or less than normal.

Pipe Entrances

To demonstrate the performance of different pipe entrances, it will be necessary to insert the pipe headwall (see Fig. 6). This is a structure 10 inches high and the width of the channel with a base 5 inches long and a plastic collar in the lower area of the wall which protrudes 3/4 inch on each side of the wall to receive and hold the conduit and various pipe entrance models. The headwall

should be inserted into the channel with the rubber seals and the base projecting upstream. The 3/4-inch, round-headed screws are to be used to hold the headwall in place. The headwall should be maneuvered so that the countersunk holes in the base are centered over the third pair of holes tapped in the channel floor downstream from the headgate. Although there are two holes in the base, a single screw is sufficient to hold the headwall in place.

In order to reduce the danger of the channel overflowing, the headwall does not extend to the top of the channel. An extension is provided to raise the headwall when a higher headpool is desired, such as when demonstrating the drop inlet entrance. If the extension is used, the headpool level must be carefully controlled to prevent overflowing the channel.

Unless it is desired to show the effect of short pipes, the conduit (the straight length of pipe about 2.5 feet long with a supporting bracket and collar at the downstream end, shown in Fig. 18) should be slipped into the pipe headwall coupling on its downstream side. An outlet should be inserted into the coupling at the downstream end of the conduit. As the outlet models are a study in themselves, it is suggested that the straight outlet (the straight piece of pipe 12 inches long, also shown in Fig. 18) be used when demonstrating inlets. For uninterrupted flow, the conduit sections must create one continuous section within the headwall collar.

It is interesting to note the different performance of the various types of inlets at different slopes. For example, the well-rounded entrance will flow full at a steep slope, whereas the square-edged entrance and the re-entrant entrance will not flow full at the 6 degree slope but may flow full at a 0 degree slope. If a single demonstration is to be made it is suggested that the 6 degree slope be used.

The efficiency of each inlet can be observed by adjusting the flow so the headpool is steady at some level. Without changing the position of the discharge valve, turn the power switch off and allow the headpool to drain. Change the inlet to some other type and again permit the pool level to come to a steady elevation. The difference between the levels is a measure of the relative efficiency of the inlets, the flow through the more efficient inlet stabilizing at the lower level. This procedure has been used in producing Figs. 6, 7, 11, 12, 14 and 15.

The effect of surface tension on these small models may sometimes cause the water to cling to the inside of the pipe. In large models and full size

pipes, the clinging is proportionately much less. The clinging must be prevented if the small laboratory models are to properly represent field conditions. Rubbing the inside of the entrances with paste wax will prevent the clinging. A good grade of car wax is suitable for this purpose.

To demonstrate the above mentioned entrances, a headpool level should be established with the headgate open enough to eliminate turbulence yet closed enough to prohibit surface roughness. To assure a sufficient headpool depth for the more efficient models, a headpool level about an inch from the top of the headwall should be established with the re-entrant entrance (the least efficient inlet) in place.

Re-entrant Entrance

A re-entrant entrance is one which protrudes from the headwall into the headpool. The straight re-entrant entrance is a straight piece of pipe about 6 inches long which fits into the headwall. It is to be inserted in the upstream side of the headwall coupling. The pipe is tapered toward the upstream end to form a sharp entrance.

There is considerable contraction at the entrance created by the change in direction of the flow of the water as it enters the entrance. The contraction prevents the pipe from flowing full.

At a slope so steep that the pipe will not flow full, the discharge coefficient is about 0.51. That is, the ratio of the actual discharge through the pipe to the theoretical discharge is 0.51. However, if the outlet is submerged or the pipe is artificially caused to flow full, the entrance discharge coefficient will be about 0.75.

When beginning the demonstration of this model, the discharge valve should be almost at Position 0. As the headpool fills, slowly increase the discharge to a valve setting of 0.5. It is necessary to start with a low flow as the beginning surge of the flow at Position 0.5 may cause the entrance to prime. It is not normal for this entrance to prime without help from turbulence, submergence or some other factor.

Square-Edged Entrance

If the re-entrant entrance is replaced by the square-edged entrance

(this entrance has its own headwall and is distinguished from the other such entrances by the square entrance edge) without changing the discharge rate (Position 0.5), the headpool level will drop. The headwall on the entrance serves to reduce the contraction. The discharge coefficient for this entrance is about 0.82. Although this is more efficient than the re-entrant entrance, the pipe ordinarily does not flow full on a 6 degree slope.

Fig. 6.--Pipe Headwall and Well-Rounded Entrance

Well-Rounded Entrance

The well-rounded entrance (shown in Fig. 6 and identified by the smooth rounding of the entrance edge) has a radius of rounding of 14 per cent of the pipe diameter. The coefficient of discharge is about 0.98. The pipe flows full on all slopes. This entrance will handle considerably more discharge than the entrances mentioned above, as indicated by the lower headpool level for the same discharge valve setting.

Fig. 7.--Tongue and Groove Pipe Entrance

Tongue and Groove Concrete Pipe Entrance

This is a 1/12 size model of an 18-inch concrete pipe tongue and groove joint with the bell end upstream. It may be identified by the two distinct step-like edges which form a groove at the entrance edge. The inside diameter of the bell is 1.15 pipe diameters. This may be compared with 1.28 pipe diameters

to the point of tangency for the well-rounded entrance. The entrance, which is typical of concrete pipe, is not as efficient as the well-rounded entrance as can be seen by noting that the pipe is not full in Fig. 7 (tongue and groove entrance) whereas it is full in Fig. 6 (well-rounded entrance).

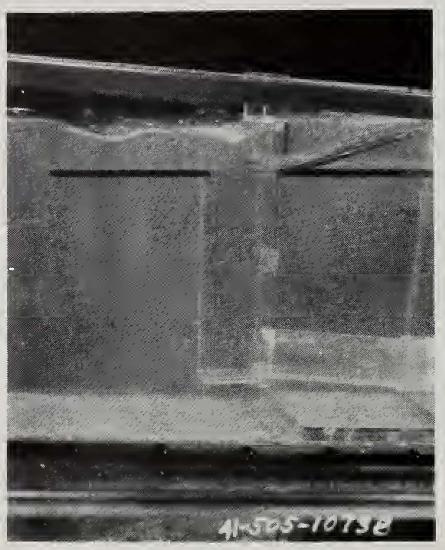

Fig. 8.--Square Drop Inlet

Square Drop Inlet

The square drop inlet [1]* is shown in Fig. 8. The riser is 5 pipe diameters deep by 1.25 pipe diameters square with the conduit on about a 4.5 degree slope. (At this conduit slope the approach floor of the entrance is level.) The design head is 2 inches over the approach floor. The headgate should be open about 100 degrees to reduce the turbulence just over the end of the approach floor.

The drop inlet is inserted upstream from the pipe headwall. With this inlet, the headwall extension is necessary and the headpool level must be watched very closely as it is very near the top of the channel (a maximum discharge valve setting of 0.5 is sufficient). The straight outlet should be used on the end of the conduit.

Although there is considerable fluctuation of the water level in the riser at intermediate flows, the height of the riser is sufficient so that the structure "primes" or flows full without headpool fluctuations. It is believed that the turbulence at the foot of the riser and in the entrance of the barrel is the predominant factor in causing the barrel to prime. As long as air is carried through the structure, the head-discharge relationship is controlled by the weir crest at the inlet and the headpool level changes slowly as the discharge increases. When air flow stops, the control is by pipe flow and small changes in flow cause large changes in headpool level--a feature that makes this type of spillway an excellent flood control device.

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* Numbers in brackets refer to appended references.

The dike extending from the tangential headwall of the structure to the channel's headwall extension prevents the flow from circulating around the headwall and causing a reduction in the capacity of the spillway.

Circular Drop Inlet [2]

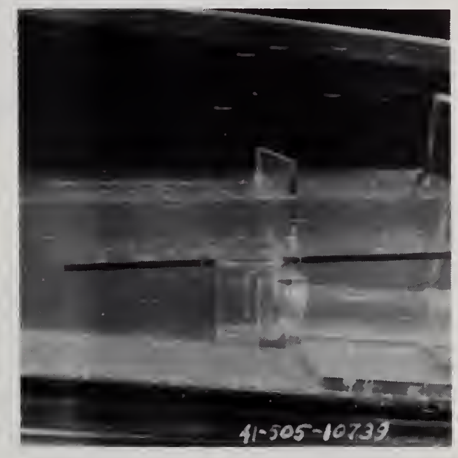

Fig. 9.--Circular Drop Inlet with Tangential Headwall

Fig. 10.--Circular Drop Inlet with Diametrical Headwall

The circular drop inlet shown in Figs. 9 and 10 has a well-rounded entrance at the drop inlet crest, a drop inlet 1.5 pipe diameters in diameter with a riser height of 2 pipe diameters. The entrance to the barrel was formed as if by wrapping sheet metal around the outside of the barrel and extending it to the inside of the sides of the drop inlet. The groove end of the barrel was not filled in or rounded off.

The inlet should be inserted into the upstream side of the headwall. The channel slope should be 6 degrees and the discharge valve setting about 0.67. The head over the approach floor should be about 2 inches.

There tends to be considerable vortex action over the inlet if some inhibiting device is not used. A tangential anti-vortex wall, Fig. 9, may be used but a diametrical headwall, Fig. 10, is more effective. These walls are provided as accessories to the inlet structure and have brass pegs which fit into the small holes provided in the approach floor. The protrusions on the walls fit into the entrance of the inlet.

Hood Inlets [3]

Inverted Hood Inlet.--To demonstrate the inverted hood inlet, insert the hood inlet model tightly into the headwall coupling with the hood, or long side, down as shown in Fig. 11. The conduit should be on at least a 10 per cent (6 degree) slope, however, the more steep the slope the more magnified the performance of the inlet. As with all the models, a headpool level similar to that shown should be established. Even with a relatively deep headpool, the conduit does not prime but runs only about half full.

Fig. 11.--Inverted Hood Inlet

Hood Inlet.--After establishing a headpool level and observing the action of the inverted hood inlet, turn off the power and allow the headpool to drain. Now turn the inlet 180 degrees so the hood overhangs the invert as shown in Fig. 12. Turn the power on and allow the headpool to again stabilize. Do not change the discharge valve setting. Observe the decreased headpool level and the flow through the conduit.

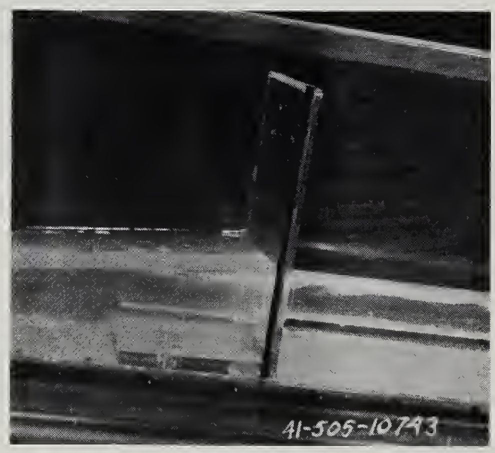

Fig. 12.--Hood Inlet

The distinguishing feature of the hood inlet is that the headpool level required for priming and for the beginning of full pipe flow are quite low. There is little increase in headpool level but a great increase in the rate of flow from the time the inlet primes until the conduit flows full of water.

Fig. 13.--"Ears" which cause the Hood Inlet to Prime

A hood length 3D/4* is recommended as the minimum satisfactory length. Tests have shown that if the hood length is too short, the pipe will probably not prime no matter what the head might be.

Ears.--Fig. 13 shows the formation of "ears" inside a hood inlet. These ears are a local rise of the water surface that triggers the priming action. As the head increases, the ears grow until they join together and the inlet primes. The formation of ears can be observed if the discharge is very slowly increased. As the headpool level rises above the midpoint of the entrance diameter, the water surface on the inside of the pipe will gradually rise above the water surface on the outside of the pipe. Eventually, these rises in the water surface, or ears, will join at the crown of the pipe and the pipe will seal off.

If the pipe, or conduit, is on a 6 degree or steeper slope, it will take a considerable increase in the discharge from the time the ears first touch at the crown until the pipe flows completely full of water only.

Vortex Inhibitors.--Vortices are not always present at the entrance to an inlet but the discharge is unpredictable when they do occur. At times there may

Fig. 14.--Splitter Wall Anti-vortex Device on Hood Inlet

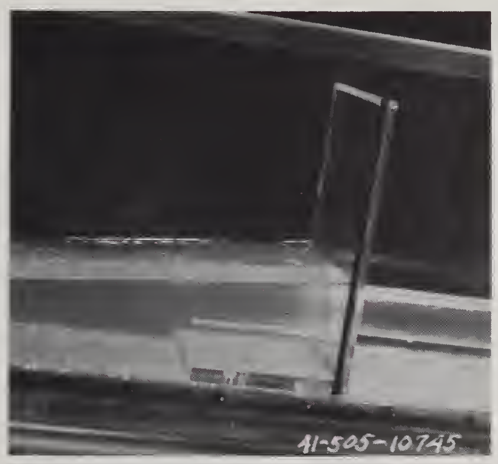

Fig. 15.--Circular Anti-vortex Device on Hood Inlet

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* D being the diameter of the conduit.

be only surface circulation but at other times a vortex core may extend into the inlet admitting air into the conduit. This can reduce the discharge of the conduit to one-third or less of its potential capacity.

The vortex inhibitors described in the next two paragraphs are designed to control the vortices so that they will not affect the spillway capacity.

The splitter wall anti-vortex device model is a thin piece of plastic 5.25 by 1.5 inches with a projection that slips into the bracket mounted on the outside crown of the hood inlet as shown in Fig. 14. It performs with uniformly satisfactory results. The minimum splitter wall dimensions are 1 D high by 3.5 D long mounted with a 2 D portion of the wall protruding beyond the inlet.

A circular anti-vortex plate is shown in Fig. 15. (A square plate is equally as good.) The plate has an arm that fits onto the top of the hood inlet in much the same manner as does the splitter wall above. The minimum diameter should be 1.5 D mounted with one-half the plate protruding beyond the end of the inlet hood. This device gives an even better performance than the splitter anti-vortex device.

Open Channel Flow

Hydraulic Jump

The bare channel is used to demonstrate the hydraulic jump (Fig. 16). With the channel on a 1 degree slope, the tailgate parallel with the channel floor (Position 6), and the headgate open about 15 degrees, a discharge valve setting of about 1.5 should produce a good illustration. When flow is established, lift the tailgate to Position 4 to back water up to form the jump.

The hydraulic jump is a standing wave having a velocity exactly equal in magnitude but opposite in direction to the velocity of the oncoming flow. The high velocity flow approaching the jump is changed to low velocity flow after it passes through the jump. Depth changes take place as a series of surface pulsations with practically no change in total head. This change in depth has the form of a breaking wave; that is, a turbulent surface roller below which the oncoming flow expands [4].

The jump may move upstream. If, in demonstrating it, the jump moves too far upstream, the tailgate may be too high. Although the channel can be on a

zero degree slope for this demonstration, it is suggested that the channel be placed on a slight slope. This will help stabilize the position of the jump in the channel.

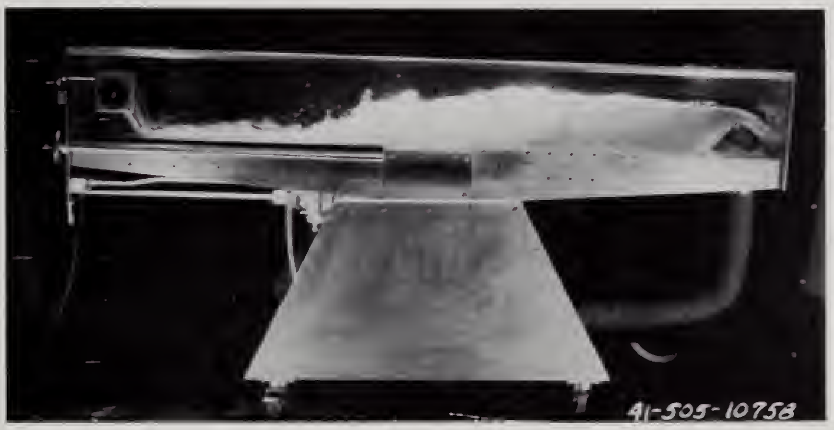

Fig. 16.--Hydraulic Jump

Much energy is used up in the jump turbulence; the hydraulic jump is a good energy dissipator.

Flow on an Adverse Slope

Water is made to run uphill because of the pressure of the water in the headbox; that is, behind the headgate. The energy required to cause the water to

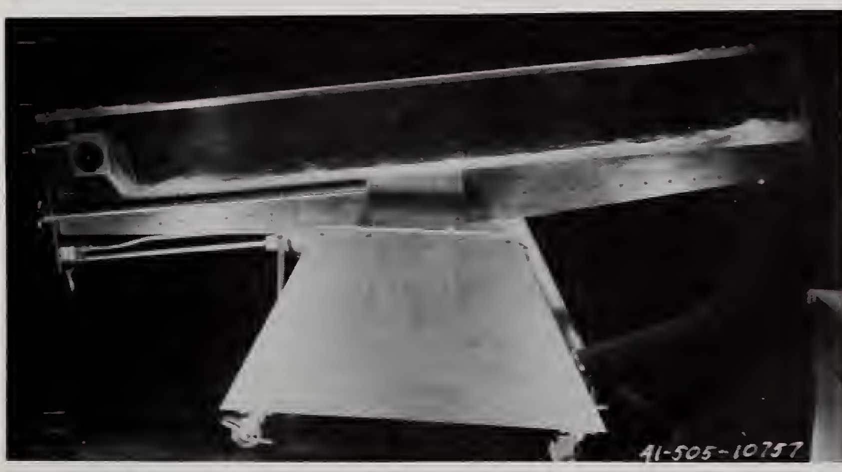

Fig. 17.--Flow on an Adverse Slope

flow uphill is obtained by slowing down the water. This change in velocity causes a change in the depth and the energy evolved from this change is used to carry the water up the incline. It can be observed that the depth of the water at the head of the channel is less than the depth of the water at the exit end of the channel.

Adverse flow, or flow running uphill (Fig. 17), is demonstrated by beginning with the channel on a positive slope, the headgate open about 15 degrees, the tailgate level with the channel floor (Position 6) and the flow discharge valve set at about 1.5. After establishing the flow in this position, increase the discharge to Position 2 and tilt the channel to a minus 6 degree slope.

Outlets

Pipe Outlets

Two simple conduit outlets are shown in Figs. 18 and 19. Both demonstrations should be conducted with the channel at a 6 degree slope. The discharge valve setting is 0.5, the headgate between 45 and 60 degrees and the tailgate set at Position 3.

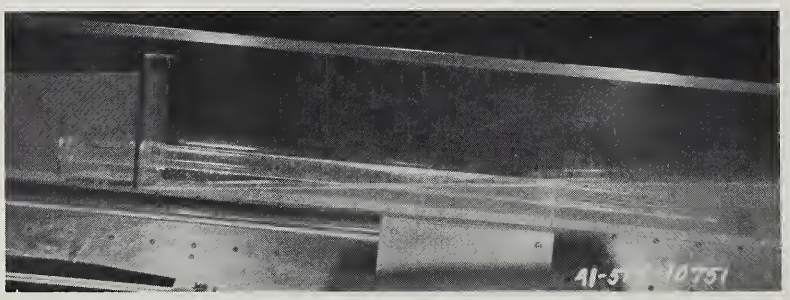

Fig. 18.--Pipe Outlet of Uniform Diameter

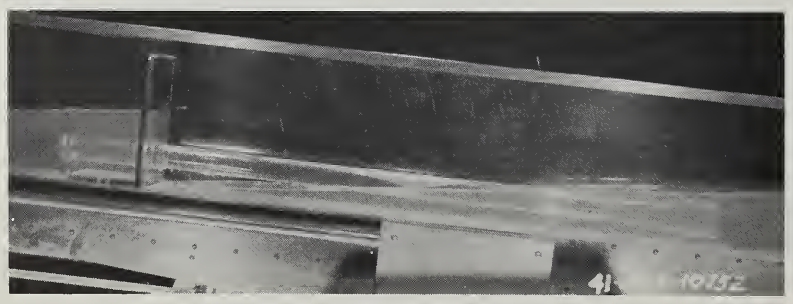

Fig. 19.--Flared Outlet

The purpose of this demonstration is to show that by increasing the diameter of the pipe exit, much of the velocity head in the pipe is recovered in the outlet. Because the area at the exit end of the flared outlet is twice the area at the exit end of the straight outlet, only a little more than one-fourth as much of the velocity head is lost at the exit of the flared outlet as at the exit of the straight outlet.

To perform these demonstrations, the exit end of the outlet must be submerged. The tailgate is to be raised to a position high enough to cause the flared outlet to be submerged about one-half inch. This setting is then used for the demonstration of the straight outlet. The well-rounded entrance should be used for the demonstrations.

The straight outlet should be shown first. Using the settings indicated above, allow the headpool to stabilize. Without turning off the flow (this saves demonstration time as the headpool is slow to stabilize), replace the straight outlet with the flared outlet. Notice that the headpool level drops. The amount of drop in the headpool level indicates the amount of velocity head that has been recovered in the flared outlet. It is evident therefore that the flared outlet makes the more efficient use of the pipe, permitting more water to be carried through it.

Straight Drop Spillway Stilling Basins

Straight Overfall.--The straight overfall is a heavy plastic wall 5.25 inches high and the width of the channel. It is a structure in itself but is also used as the headwall for the several stilling basins to be discussed in this section.

The straight overfall is to be inserted with the projection on the upstream side and with the rubber seals facing upstream. (The seals slide in place easier if they are lubricated with water.) Round head screws are used to hold the overfall in place in the fourth or fifth set of tapped holes from the headgate. The channel slope is zero.

The design head for the overfall is 2 inches over the crest. When starting the model, the nappe may cling to the downstream face of the weir. The nappe will spring away from the weir if a finger is inserted through it.

It will be noted that the water behind and under the nappe is higher than the downstream level. This is partly due to the force exerted by the nappe hitting the bed of the channel and partly because the suppressed weir is not aerated. The air behind the nappe is slowly entrained and exhausted into the atmosphere. This

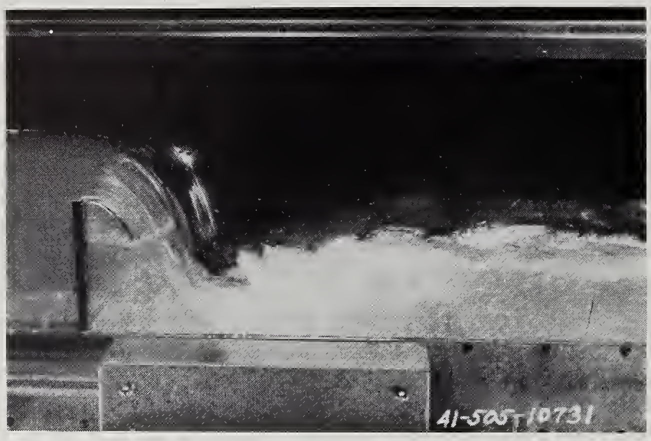

Fig. 20.--Straight Overfall

creates a partial vacuum under the nappe and causes the nappe to be depressed and the water behind the nappe to rise still further.

The tailwater level can be varied to show 1) shooting flow away from the weir, 2) the hydraulic jump at the base of the weir as in Fig. 20, 3) the nappe plunging into the tailwater pool, 4) various degrees of submergence, and 5) the point at which submergence affects the headwater level.

The next four demonstrations are of half models of symmetrical structures which have been split down the centerline. The cut side is inserted against the channel wall so that the action beneath the nappe and in the stilling basin can be observed more easily. Each of these models is set against the downstream side of the straight overfall and held in place by a single flat head screw inserted into the first tapped hole in the channel bed below the overfall. The recommended discharge valve setting is 1 with the headgate open 65 degrees and the channel on a 0 degree slope.

Straight Drop Spillway with Plain Apron.--The model of this straight drop spillway is 10 inches long with the sidewalls parallel and the wingwall perpendicular to the centerline. The apron is plain having no blocks or sills to dissipate the energy of the flow from the spillway. A design head of 2 inches over the crest and a tailwater depth of 2.2 inches above the floor level have been established for this spillway. The tailgate setting for this demonstration is Position 5+.

Fig. 21.--Straight Drop Spillway with Plain Apron

The contraction of the flow at the crest tends to aerate the nappe, thus preventing the formation of a vacuum under the nappe. This is shown by comparing Figs. 20 and 21, noting the depth of water built up behind the nappe.

Wisconsin Notch Spillway Stilling Basin.--The Wisconsin notch spillway stilling basin, Fig. 22, was studied by Kessler at the University of Wisconsin [5].

The model is 16 inches long with two transverse sills on the apron, the second a little smaller than the first. It has been designed for a head over the crest of 2 inches and a tailwater depth of 2.2 inches above the floor in a level channel. To obtain these depths, the channel should be on a slope of 0 degrees with the headgate open about 65 degrees, the tailgate at Position 5+ and the discharge valve setting just less than 1.

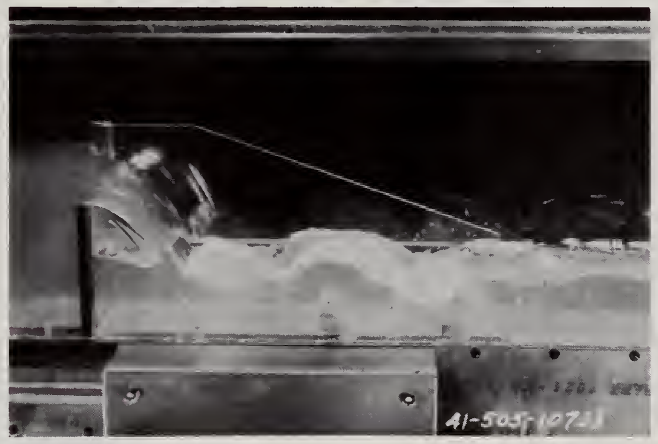

Fig. 22.--Wisconsin Notch Spillway Stilling Basin

In the model, the water flows along the basin floor, hits the first sill, bounces, and falls just beyond the edge of the second sill. There is some energy dissipated by the sills but not enough to prevent the formation of a scour hole in the downstream channel.

Morris-Johnson Straight Drop Spillway Stilling Basin.--The Morris-Johnson outlet model [6] shown in Fig. 23 is designed for a head of 2.34 inches over the crest and a tailwater depth of 3.12 inches over the end sill. A tailgate position of 4.5 should give the desired tailwater depth. It is much shorter than the Wisconsin notch spillway and has but one transverse sill which is located at the end of the apron. In observing the performance of this basin, it will be noticed that the end sill causes a standing wave. Where this wave plunges into the tailwater, excessive scour may result. Also, the high boil along the basin sidewall is conducive to bed and bank scour along the side of the downstream channel. The longitudinal sills are flow-straightening devices placed on the apron which are intended to reduce the bank scour caused by high velocity flows leaving the stilling basin.

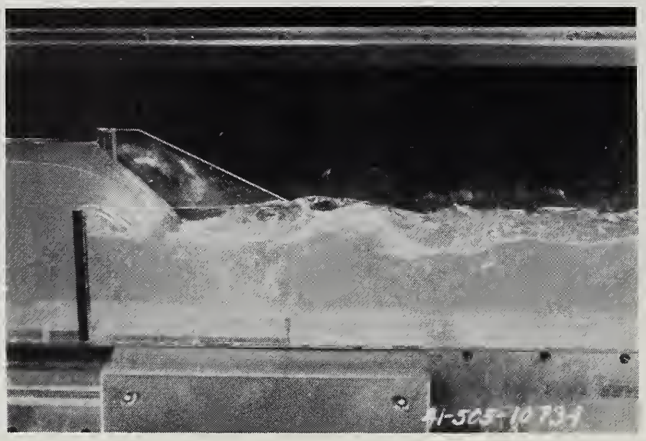

Fig. 23.--Morris-Johnson Straight Drop Spillway Stilling Basin

Straight Drop Spillway Stilling Basin.--The straight drop spillway [7], Fig. 24, is a straight overfall weir. The water flowing over the spillway falls onto a horizontal apron where the energy is dissipated by means of blocks, sills and tailwater. The water is discharged into the downstream channel in such a way as to prevent damaging scour.

The design head over the crest of this model

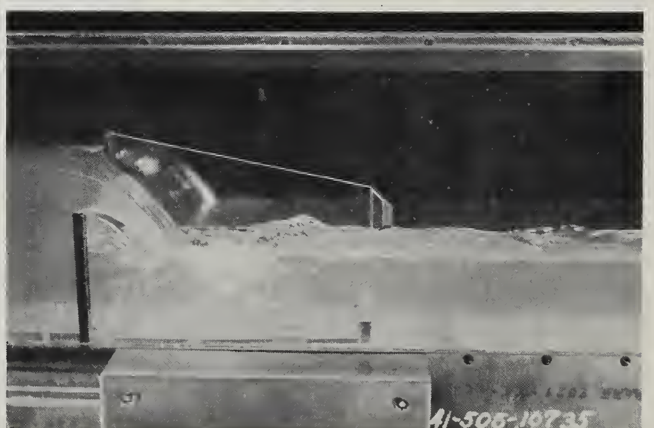

Fig. 24.--Straight Drop Spillway Stilling Basin

is 2 inches with a tailwater depth of 2.5 inches over the end sill. To obtain this tailwater depth requires a tailgate setting of 5.25.

One of the factors determining the length of the basin is the point at which the nappe hits the basin floor. A sufficient distance is required between this point and the floor blocks to permit the stream to become approximately parallel to the floor before it reaches the blocks. If this distance is too short, the nappe hits the blocks and they become ineffective.

The width and spacing of the floor blocks should be such as to break up the stream into small enough segments to dissipate the high-velocity flow in a short distance. If they occupy too much space, they act as a solid sill and, if they are too small, they are ineffective. The floor blocks prevent bank erosion downstream of the spillway and the end sill prevents scour in the stream bed.

It can be observed that the sidewalls are high enough so they are not overtopped by water surface fluctuations or by the normal turbulence within the stilling basin. It should be noted how smoothly and evenly the flow leaves the stilling basin. The water is discharged into the downstream channel in such a way that no bed scour is caused.

The performance of the straight drop spillway stilling basin can be compared with the performance of the Wisconsin notch spillway stilling basin and the Morris-Johnson straight drop spillway stilling basin. All three structures are designed to do the same job but the straight drop spillway stilling basin does it much better than the other two.

This structure can be used as an erosion control structure in gullies, as a grade control structure in drainage ditches, as an irrigation drop and check structure, and as a spillway for earth dams.

Box Inlet Drop Spillway and Stilling Basin

The box inlet drop spillway [8] and outlet shown in half model in Fig. 25 should be placed near the center of the channel and held fast by a 1/2-inch flat head screw inserted into a tapped hole in the channel floor. It has been designed for a head over the crest of 3 inches and a tailwater depth of 2-15/16 inches above the apron floor. These depths are established by opening the discharge valve to Position 1.25 and setting the tailgate almost at Position 5.

Because of the long crest of the box inlet, large flows can pass with relatively low heads, yet the spillway width need be no greater than that of the downstream channel.

Fig. 25.--Box Inlet Drop Spillway and Stilling Basin

The flow, directed to the inlet by the headwall, enters over the upstream end and two sides of the inlet and passes through the open downstream end into the outlet structure. Here the longitudinal sills straighten out the flow and prevent direct action of the stream on the banks. Before leaving the spillway, the flow passes over an endsill which deflects the flow and decreases the depth of the scour hole in the stream bed.

The box inlet drop spillway is used as an outlet to control vertical drops of from 2 feet to 12 feet, and as a drainage structure to permit surface water to enter drainage ditches without causing erosion of the banks. In highway use, the so-called straight section of the outlet can be lengthened and covered to form a culvert.

<u>Box Inlet Chute Spillway</u>

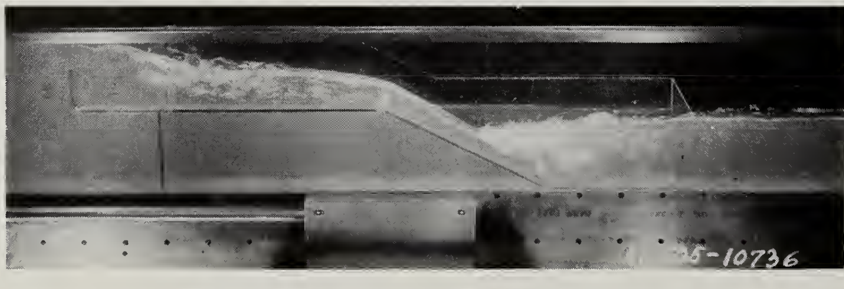

Fig. 26.--Box Inlet Chute Spillway and SAF Stilling Basin

The largest model of the set is a half model of the combination of a box inlet drop spillway, a chute and a SAF stilling basin. It fits into the center of the channel, as shown in Fig. 26, and is held in place by turning the plastic screws until they are snug against the sidewall. The screws should not be turned too tightly; only tight enough to hold the model firmly in place.

The orange line on the wall of the model represents the computed critical depth of flow in the level section. In the chute section, it represents the computed drop down curve for which the critical depth of flow at the upstream end of the chute has been used as a beginning point for the computation. In demonstration, the water surface should duplicate the drop down curve. It will be noted that the assumption of critical depth at the chute entrance was found to be in error and that the actual depth of flow is less than the computed critical depth. However, it will be observed that the actual depth of flow in the chute coincides with the computed depth of flow except for a short distance at the entrance to the chute.

With the channel at a 0 degree slope and the headgate sufficiently open to prevent excess turbulence in the headpool, a discharge valve setting of slightly greater than 1 and a tailgate position of about 3.5 will bring the headpool and tailwater depths to the levels indicated by orange lines on the headwall and wingwall, respectively. If these two levels are maintained, the depth of flow in the chute will be correct.

Here again care should be taken when setting the discharge valve for the demonstration as the headpool is so near the top of the channel that a slight excess of discharge will cause the channel to overflow.

Closed Conduit Spillway and Stilling Basins

The general setup for the demonstration of stilling basins is shown in Fig. 27. The parts shown, from upstream to downstream are: a well-rounded inlet, pipe headwall, conduit, transition, and a hydraulic jump stilling basin.

A downward channel slope of 6 degrees (10 per cent) will put the stilling basin floor in a horizontal position. The headgate should be open 3 to 4 inches with a discharge valve setting of about 0.5. Any inlet may be used to demonstrate the stilling basins but it is recommended that the more efficient entrances be chosen; that is, a well-rounded entrance or a hood inlet.

The pipe headwall is to be installed as for the pipe entrance demonstration but in the second set of holes from the headgate.

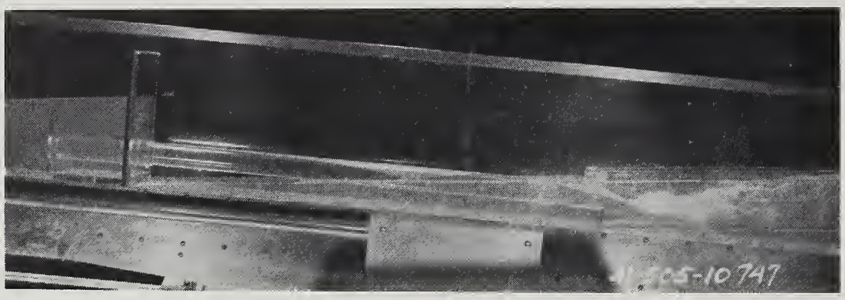

Fig. 27.- Closed Conduit Spillway Setup
for Demonstrating Stilling Basins

The transition is inserted into the collar at the downstream end of the conduit. Its purpose is to change the cross section from circular at the pipe exit to rectangular at the stilling basin entrance. The sidewalls flare and the floor is on the same slope as the conduit. The roof of the transition is raised so the jet will not cling to it, thereby causing poor flow distribution.

A filler, a trangular piece which fits over and inside the roof of the transition and is held in place by a screw, has been provided to fill in the raised portion of the transition roof. When the filler is in place, the jet will cling to the center or to either side of the roof of the transition causing an uneven depth distribution across the transition. Without the filler, the water will break away from the crown of the transition and a uniform depth of jet across the width of the transition can be depended upon. The filler should be removed for these full model stilling basin demonstrations.

The full model stilling basins are constructed with lips that slip over the vertical wall at the exit of the transition to hold them in place in the channel. Care should be taken in the assembly and dissassembling of these parts to avoid breaking the lips. The models should be moved vertically and not with the sidewise motion required when setting rubber seals in place. The basins are held firm by a 1.25-inch long flat head screw in the basin floor.

Hydraulic Jump Stilling Basin.--The hydraulic jump stilling basin is shown in Fig. 28. The sides are parallel and the basin length is five times the

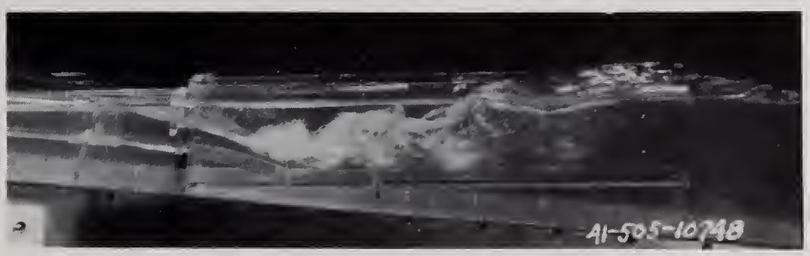

Fig. 28.--Hydraulic Jump Stilling Basin

downstream depth of the hydraulic jump. For demonstration, the discharge valve setting should be 0.5 and the tailwater depth above the basin floor should be 3.28 inches (a tailgate position of 2.67) to produce the hydraulic jump within the basin. The tailwater level determines the location of the jump--decreased tailwater causes the jump to move downstream and out of the stilling basin, while an increase in tailwater depth will drown the jump and cause the basin to fill back into the transition.

The tailwater depth should be great enough so that the turbulence of the jump is maintained within the structure until the water energy has been dissipated to a point where it will not damage the downstream channel.

U. S. Bureau of Reclamation Rectangular Stilling Basin.--The length and depth necessary to form a hydraulic jump in stilling basins are reduced by the use of chute blocks, floor blocks and an end sill [9], Fig. 29. The combination of these devices permits a 40 per cent reduction in the stilling basin length and a 15 per cent reduction in tailwater depth. The tailwater depth should be 2.78 inches (tailgate at Position 3) above the basin floor measured behind the end sill.

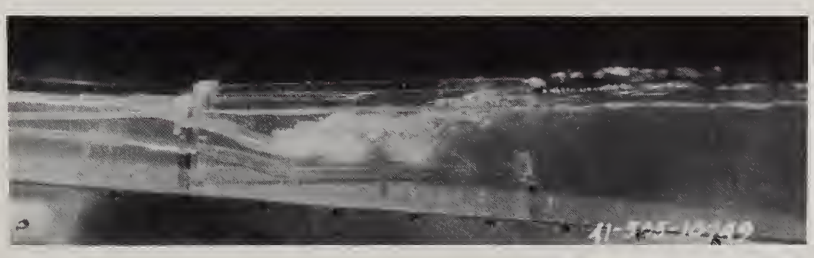

Fig. 29.--U. S. Bureau of Reclamation
Rectangular Stilling Basin

The chute blocks break up the high-velocity sheet of water entering the basin thus increasing the depth at the entrance. A greater turbulence is produced, hence greater energy dissipation. The purpose of the floor blocks and end sill is to check the high velocity flow and maintain the jump within the basin. The end sill is also effective in developing a ground roller. This ground roller prevents scour at the end of the basin and causes stream bed material to be deposited downstream from the sill.

SAF Stilling Basin.--The SAF stilling basin [10] shown in Fig. 30 was designed using sidewalls flaring 1 in 10. This flaring is the same as is used in the

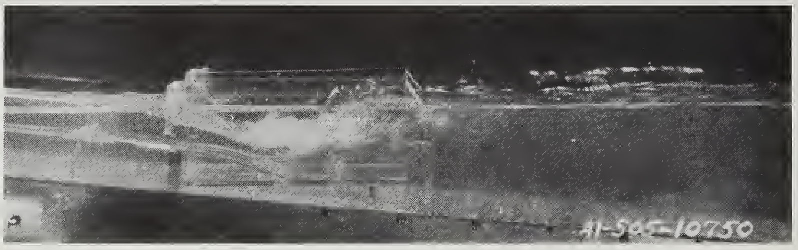

Fig. 30.--SAF Stilling Basin

transition. The basin length is 68 per cent shorter than that of the hydraulic jump stilling basin and 47 per cent shorter than that of the U. S. Bureau of Reclamation stilling basin. The tailwater depth is 3.08 inches (tailgate set almost at Position 3), 6 per cent less than for the hydraulic jump stilling basin but 11 per cent more than for the U. S. Bureau of Reclamation stilling basin, in order to keep the jump in the basin. Forty-five degree wingwalls are desirable to provide maximum protection against bank scour (angle measured from stilling basin centerline). This basin has proved to be an economical and efficient structure for dissipating the energy of the high-velocity discharge from culverts, chutes and other types of spillways.

REFERENCES

1. Blaisdell, Fred. W., "Hydraulics of Closed Conduit Spillways, Parts II through VII, Results of Tests on Several Forms of the Spillway," St. Anthony Falls Hydraulic Laboratory Technical Paper No. 18, Series B, Minneapolis, Minnesota, March 1958, pp. 24-36.

2. Ibid., pp. 36-41.

3. Blaisdell, Fred W., and Donnelly, Charles A., "Hydraulics of Closed Conduit Spillways, Part X, The Hood Inlet," St. Anthony Falls Hydraulic Laboratory Technical Paper No. 20, Series B, Minneapolis, Minn., April 1958.

4. Rouse, Hunter, Engineering Hydraulics, John Wiley and Sons, Inc., New York, 1950, pp. 71-72.

5. Kessler, Lewis H., "Experimental Investigation of the Hydraulics of Drop Inlets and Spillways for Erosion Control Structures," Bulletin of the University of Wisconsin, Engineering Experiment Station Series, No. 80, 1934, pp. 47-50.

6. Morris, B. T., and Johnson, D. C., "Hydraulic Design of Drop Structures for Gully Control, Transactions, American Society of Civil Engineers, Paper No. 2198, Vol. 108, 1943, pp. 887-940.

7. Donnelly, Charles A., and Blaisdell, Fred W., "Straight Drop Spillway Stilling Basin," St. Anthony Falls Hydraulic Laboratory Technical Paper No. 15, Series B, Minneapolis, Minn., November 1954.

8. Blaisdell, Fred W., and Donnelly, Charles A., "The Box Inlet Drop Spillway and Its Outlet," Transactions, American Society of Civil Engineers, Paper No. 2828, Vol. 121, 1956, pp. 955-994.

9. Warnoch, Jacob E., "Spillways and Energy Dissipators," Proceedings of Hydraulic Conference, Studies in Engineering, Bulletin No. 20, University of Iowa, Iowa City, 1940, p. 142.

10. Blaisdell, Fred W., "The SAF Stilling Basin--a Structure to Dissipate the Destructive Energy in High-velocity Flow from Spillways." Agricultural Handbook No. 156, Washington, D. C., April 1959.

CHANNEL CONTROL SETTINGS

Structure Model	Fig. No.	Discharge	Headgate	Tailgate	Channel Slope
Re-entrant Entrance		0 then 0.5	45° - 60°	6	6°
Square-Edged Entrance		0.5	45° - 60°	6	6°
Well-Rounded Entrance	6	0.5	45° - 60°	6	6°
Tongue and Groove Concrete Pipe Entrance	7	0.5	45° - 60°	6	6°
Square Drop Inlet	8	0.5	100°	6	4.5°
Circular Drop Inlet	9-10	0.67	100°	6	6°
Hood Inlets	11-12 14-15	0.5	45° - 100°	6	6°
Hydraulic Jump	16	1.5	15°	6 then 4	1°
Flow on an Adverse Slope	17	1.5 then 2	15°	6	0° then -6°
Straight Pipe Outlet	18	0.5	45° - 60°	3	6°
Flared Outlet	19	0.5	45° - 60°	3	6°
Straight Overfall	20	1.0	65°		0°
Straight Drop Spillway with Plain Apron	21	1.0	65°	5-1/8	0°
Wisconsin Notch Spillway Stilling Basin	22	1.0	65°	5-1/8	0°
Morris-Johnson Straight Drop Spillway Stilling Basin	23	1.0	65°	4-1/2	0°
Straight Drop Spillway Stilling Basin	24	1.0	65°	5-1/4	0°
Box Inlet Drop Spillway and Stilling Basin	25	1.25	65°	4-7/8	0°
Box Inlet Chute Spillway	26	1.0	65° - 100°	3-1/2	0°
Hydraulic Jump Stilling Basin	28	0.5	65°	2-2/3	6°
U. S. Bureau of Reclamation Rectangular Stilling Basin	29	0.5	65°	3	6°
SAF Stilling Basin	30	0.5	65°	2-7/8	6°